UWB Propagation Channel Modelling

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Abstract: This paper mainly describes modelling of IEEE 802.15.3a standard UWB propagation channel in MATLAB. A performance analysis and comparison of the UWB propagation channel in four different environments are given, based on simulations in both MATLAB and ADS.

1. Introduction

Ultra-Wideband (UWB) is a fast emerging technology. The UWB signal can be transmitted through the wide spectrum band (3.1-10.6GHz). UWB supports high speed data rates up to 448Mbps, based on ultra-short (nanosecond scale) waveforms. This narrow pulse feature causes new effects on UWB propagation channel. Comparing to "conventional" wireless channel, the very large bandwidth of the UWB impulse based signal results in a high number of multipath components and in non-Rayleigh fading.

2. UWB Propagation Channel

The modified Saleh-Valenzuela (S-V) model was adopted as a reference UWB channel model by the IEEE 802.15.3 in 2003 [2]. The modelling of UWB channels is based on the measurement of indoor propagation environment, as the main commercial applications will be indoor communications. The main distinguishing features of UWB propagation channel are its extremely multipath-rich profile and non-Rayleigh fading amplitude characteristics.

Multipath-rich profile For UWB systems, there are more multipath components as opposed to other wireless channels. As the bandwidth of the UWB waveforms can be ultra wide, different parts of the same object will give rise to several multipath components, all of which would be part of one cluster. Thus, the multipath components arrive at the receiver in clusters. Within each cluster, there are multiple subsequent arrivals called rays [3]. Therefore, for the time-of-arrival statistics, the IEEE 802.15.3a standard model used the Saleh-Valenzuela (S-V) approach, which modeled multipath components in clusters and rays.

Non-Rayleigh fading As the UWB pulse can be quite short, only few multipath components overlap within each resolvable delay bin, thus the central limit theorem is no longer applicable and the amplitude fading statistics are no longer Rayleigh. Therefore, in IEEE 802.15.3a standard model, the Rayleigh amplitude fading statistics in S-V channel is substituted by log-normal distribution [1].

3. UWB Propagation Channel Modelling in MATLAB
IEEE802.15.3a standard channel model

The modelling of UWB propagation channel is fully based on the proposed IEEE 802.15.3a Standard Model [1]. The impulse response of modified Saleh-Valenzuela model may be represented as:

$$h_i(t) = X_i \sum_{l=0}^{L-1} \sum_{k=0}^{K-1} \alpha_{k,l}^i \delta(t - T_l^i - \tau_{k,l}^i) \tag{1}$$

where $\alpha_{k,l}^i$ represents the multipath gain coefficients, $T_{k,l}^i$ represents the delay of the lth cluster, $\tau_{k,l}^i$ represents the delay of the kth multipath component relative to the lth cluster arrival time (T_l^i). X_i represents the log-normal shadowing, and i refers to the ith realization.

To study the delay characteristics of the modified S-V channel under UWB, we calculate the impulse response of equation (1) using MATLAB. The results for channel parameter identical to those in [2] are shown in Figure 1.
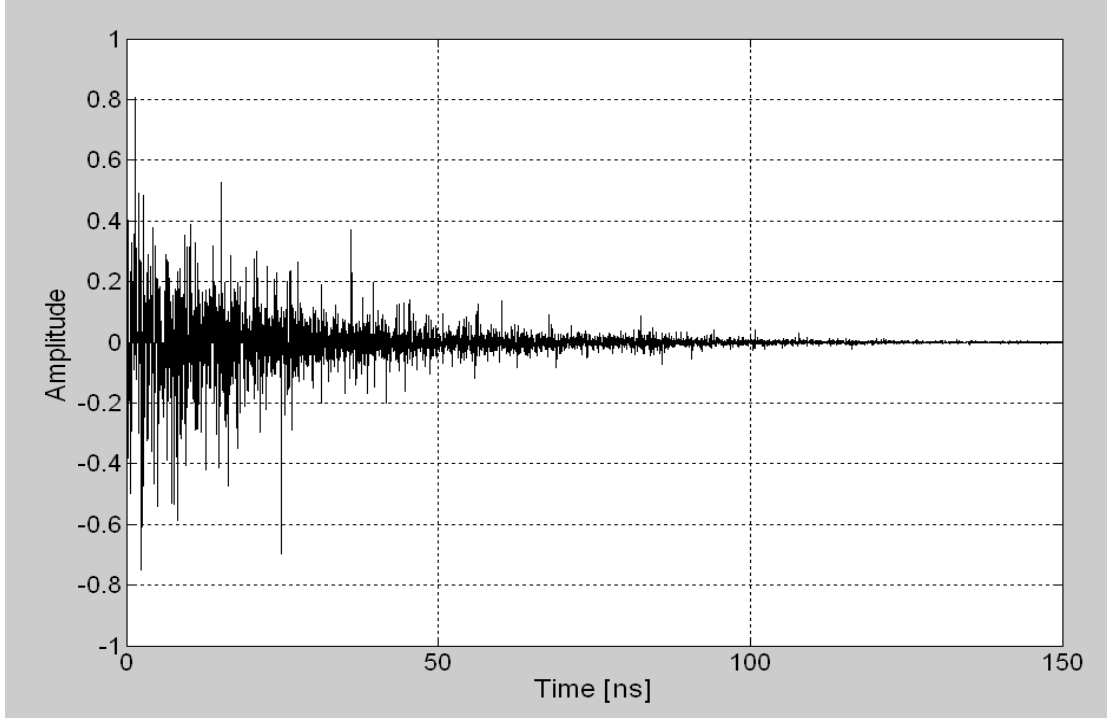

Figure 1 Delay Profiles of modified Saleh-Valenzuela channel 3

Multipath Arrival The multipath components are defined in **cluster** and **ray** as described above. Cluster arrivals are Poisson distributed with rate Λ (cluster arrival rate). Within each cluster, the ray arrivals are also Poisson distributed with rate λ (ray arrival rate), and $\lambda \gg \Lambda$. The definition assumes that within a cluster, the first ray arrives at with no delay ($\tau_{0,l} = 0$). The distribution of cluster arrival time and the ray arrival time can be presented by [1]

$$p(T_l | T_{l-1}) = \Lambda \exp[-\Lambda(T_l - T_{l-1})], \quad l > 0 \tag{2}$$

$$p(\tau_{k,l} | \tau_{(k-1),l}) = \lambda \exp[-\lambda(\tau_{k,l} - \tau_{(k-1),l})], \quad k > 0 \tag{3}$$

Log-normal fading The Rayleigh distribution in the S-V channel model is replaced by the log-normal distribution, since the latter fits the measurement environment well. Such fading was also realized in our MATLAB model following the equation in [1].

Log-normal Shadowing Due to the fact that the log-normal shadowing of the total multipath energy is captured by the term X_i, the total energy contained in the multipath gain coefficients $\{ \alpha_{k,l} \}$ may be normalized. The shadowing term is characterized by [1]

$$20\log_{10}(Xi) \propto Normal(0, \sigma_x^2) \tag{4}$$

3.2 Test of four different modified S-V channel environments
The IEEE 802.15.3a Standard Model defined four different measurement environments, namely CM1, CM2, CM3 and CM4.
- CM1: line-of-sight (LOS) model for 0-4 m
- CM2: Non-LOS (NLOS) model for 0-4 m
- CM3: NLOS for 4-10 m
- CM4: NLOS for 4-10 m, with extreme multipath channel condition.

The impulse responses of the four different modified S-V models are shown in Figure 2. It is apparent that paths in CM1 and CM2 tend to concentrate in two or three clusters with smaller delay, whereas in CM3 and CM4 paths tend to spread over more clusters and have bigger delay. This is due to their different cluster arrival rates. And the gains of paths in CM3 and CM4 decay faster due to their longer path.
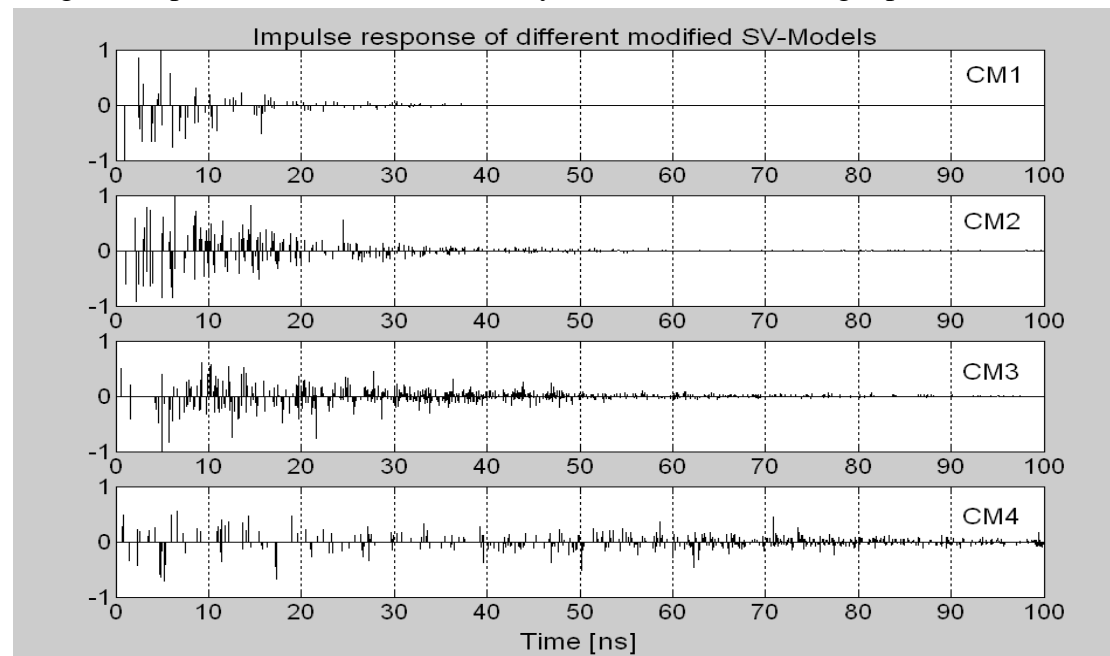

Figure 2 Delay profiles for Modified Saleh-Valenzuela channel CM1-4

4. UWB Propagation Channel Simulation in ADS
The UWB propagation channel simulation in ADS is based on the Direct Sequence UWB system (DS-UWB).We used DS techniques and BPSK modulation scheme.

The data symbol is spreaded by a Pseudo Random (PR) code into multiple chips, much as in conventional DS spread spectrum systems. Then the pulses in the sequences are shaped using a Gaussian pulse shape. A correlator receiver is used at the receiver end. Figure 3 shows the BER versus Eb/No results for four different modified S-V channels (CM1-4).
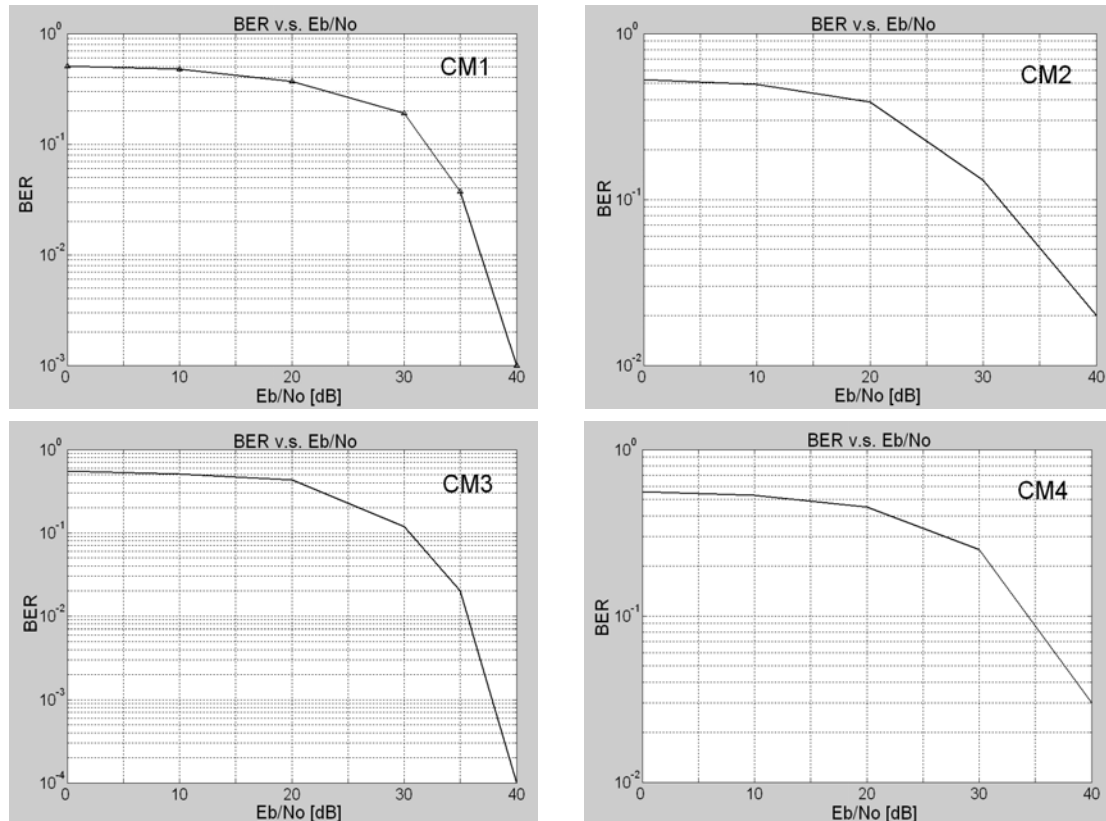

Figure 3 BER versus Eb/No for Modified Saleh-Valenzuela channel CM1-4

5. Conclusions and Future Work

Based on the Direct Sequence UWB (DS-UWB) system, we modeled and simulated the UWB propagation channel in both MATLAB and ADS. The delay profile figures from MATLAB illustrate the impulse response of the modified S-V channel and difference between four measurement environments. The BER vs. Eb/No plots further show the performance of the four modified S-V channels clearly. The models developed in MATLAB and ADS may be used for further studies of UWB systems.

6. References

[1]   J. R. Foerster, M. Pendergrass, and A. F. Molisch, "A UWB channel model for ultrawideband indoor communication", Proc. WPMC 2003, (2003).
[2]   Ian Oppermann, Matti Hamalainen and Jari Iinatti, "UWB Theory and Applications", ISBN 0-470-86917-8
[3]   Adel A. M. Saleh and Reinaldo A. Valenzuela, "A Statistical Model for Indoor Multipath Propagation", IEEE J. in communications, vol. sac-5, No.2, February 1987
[4]   Liuqing Yang and Georgios B. Giannakis, "Ultra-Wideband Communications- An Idea Whose Time Has Come", IEEE signal processing magazine, November 2004
[5]   "IEEE 802.15 Wireless Personal Area Networks – DS – UWB proposal" March 2004
[6]   Simon Haykin, "Communication Systems", 4th Ed, ISBN 0-471-17869-1